Broadband Flat-base Luneburg Lens Antenna for Wide Angle Scan

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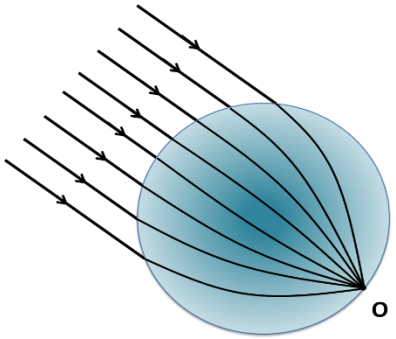
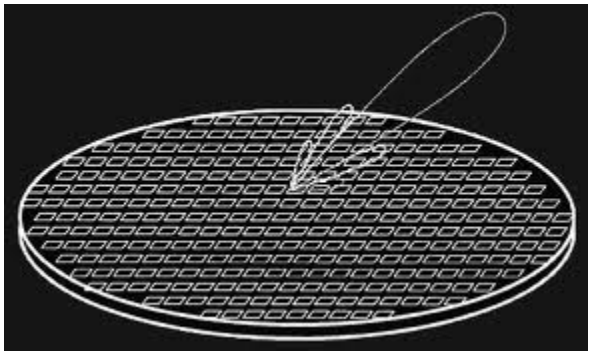
Outline

- Introduction and Motivation
- Luneburg Lens Principle and Design
- Flat-base Luneburg Lens Design
- Waveguide Array Design
- Results
- Conclusions

Introduction and Motivation

- Luneburg Lens has recently come to light as an attractive alternative to phased arrays and mechanical rotation for making antennas for large angle beam scanning applications.





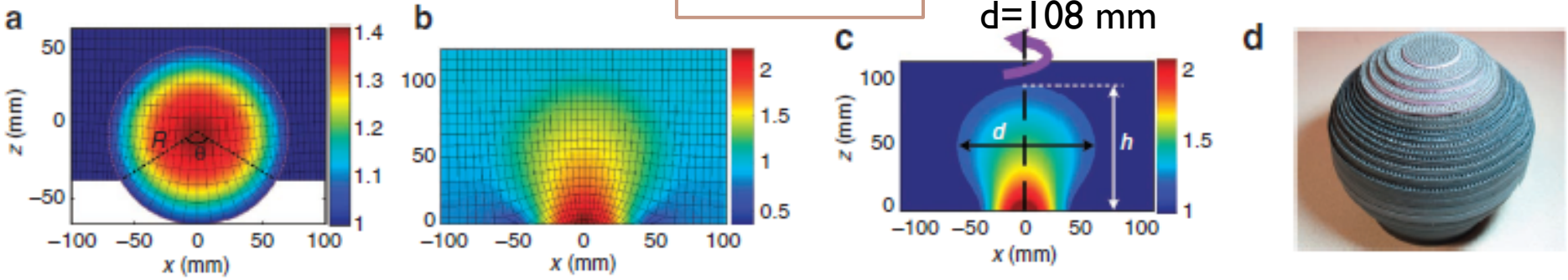
- Luneburg Lens is a spherical lens and therefore in order to scan large angles it is required to have a transmit and receive array which is conformal to the spherical surface of the lens.

Introduction and Motivation

- Transformation optics has been used to flatten one of the spherical surface of the Luneburg lens so that it is compatible with planar feed and receive arrays.
  - But it requires material with er < 1 which are difficult to fabricate with with low losses and over high band widths.
  - Therefore most researchers replace the materials with er<1 with er=1 which deteriorates the performance of the lens

Replace er<1 with er=1

h=104 mm
d=108 mm



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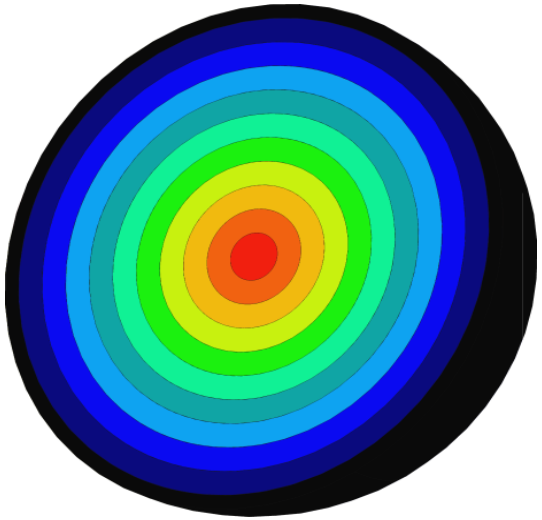
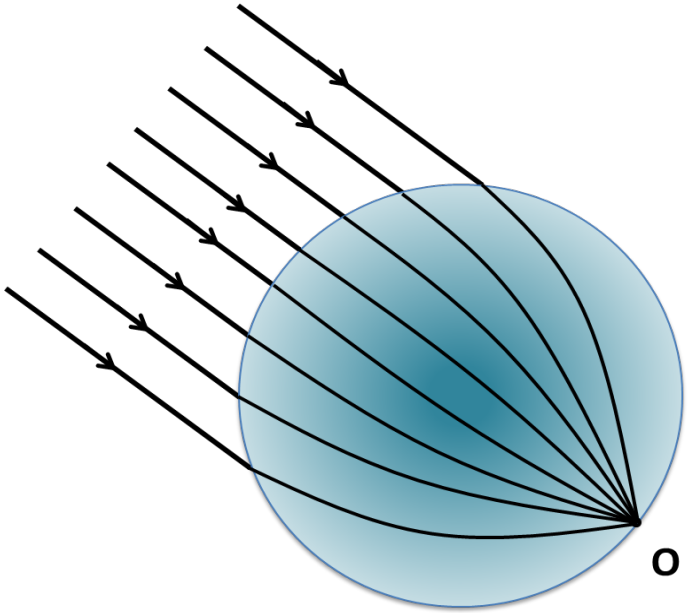
Luneburg Lens Principle and Design





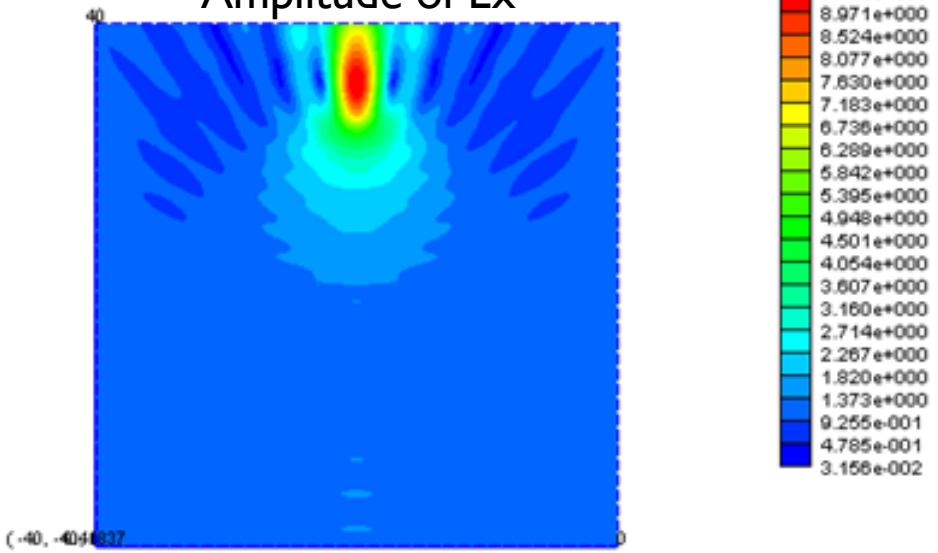
N	1	2	3	4	5	6	7	8	9	10	11
ε_r	2.0	1.96	1.92	1.86	1.78	1.68	1.56	1.43	1.28	1.11	1.05

Wavelength (λ_0)= 10 mm
Center Frequency (f_0) = 30 GHz
Diameter of the Lens = 63.5 mm = 6.35λ_0

$n = \sqrt{\varepsilon_r} = \sqrt{2-(r/R)^2}$

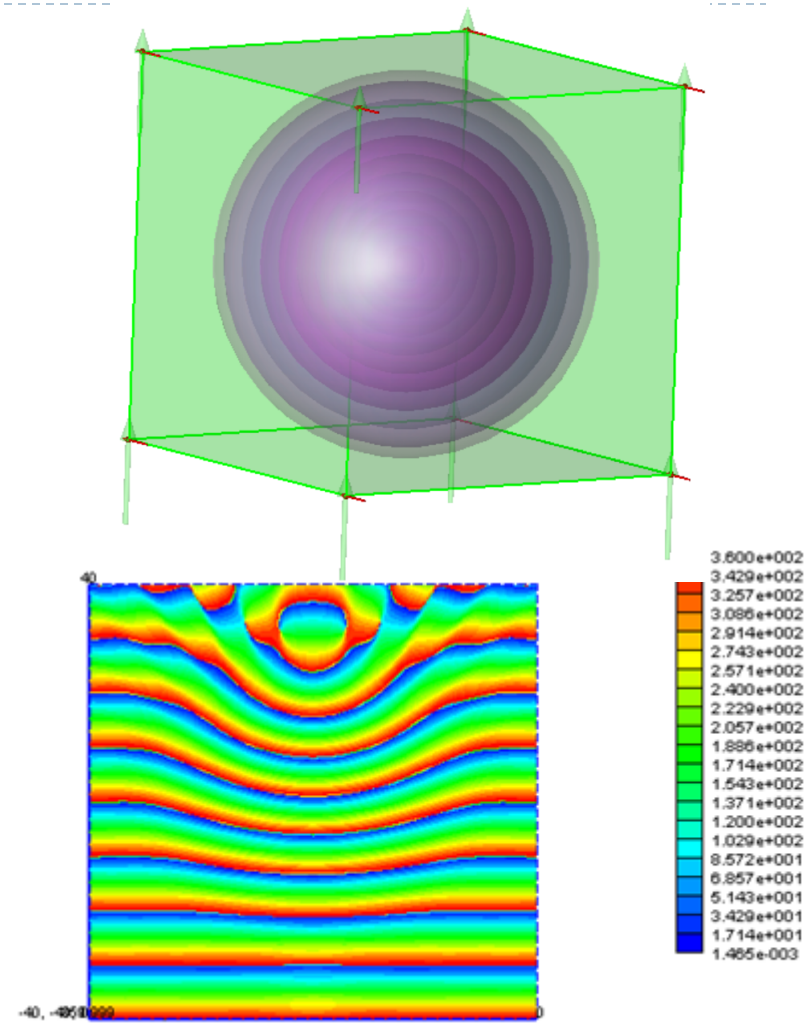
Focusing a Plane Wave

Amplitude of Ex



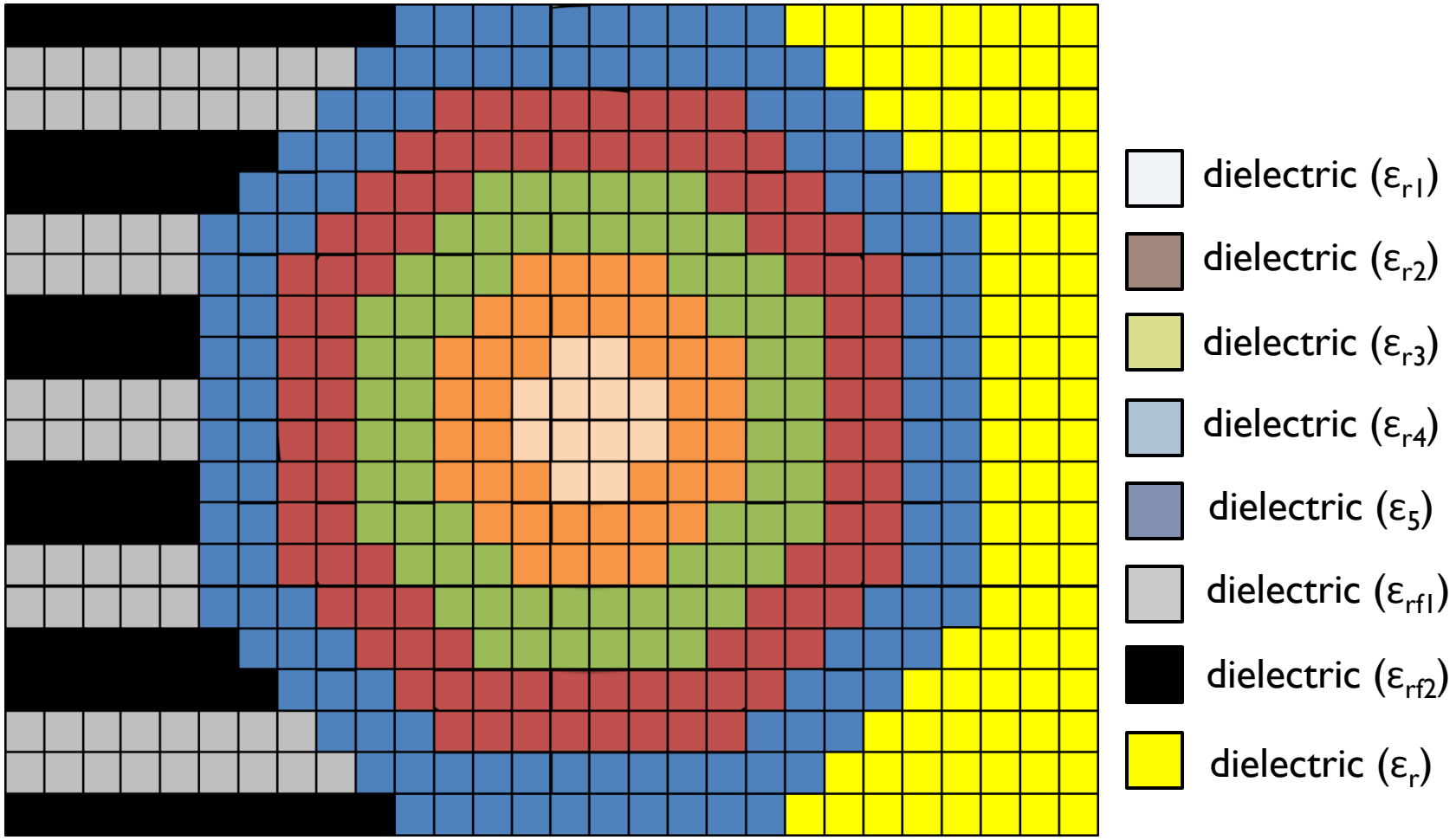
Observe the fields in a plane parallel to the direction of propagation of the plane wave and passing through the center of the lens

A plane wave gets focused at a point on the opposite end of the diameter parallel to the plane wave

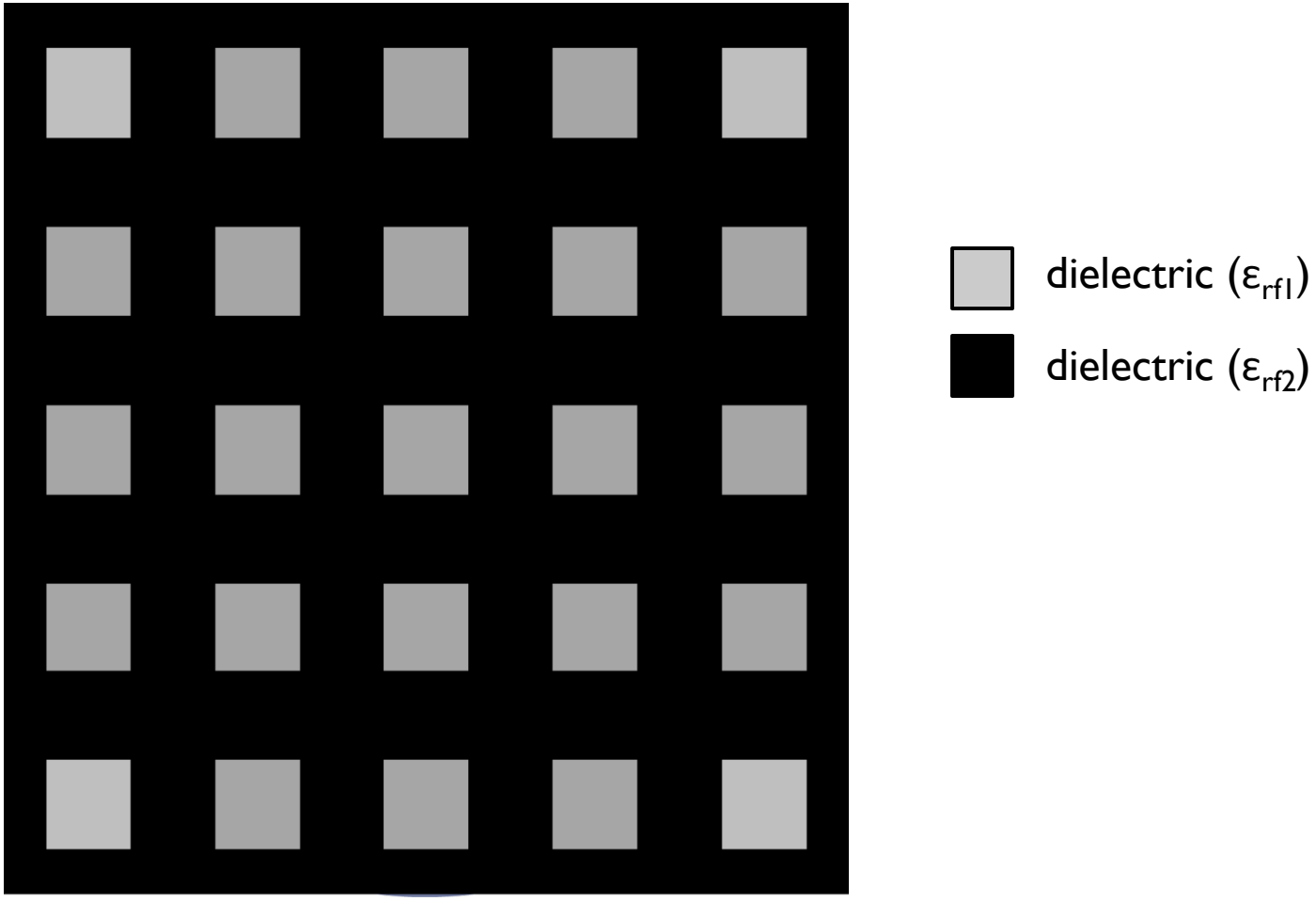


Phase of Ex

Flat base Luneburg Lens Antenna Design

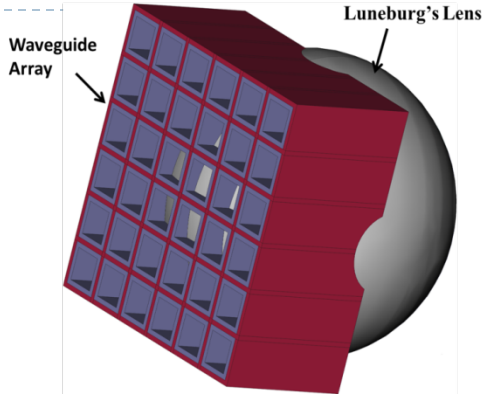


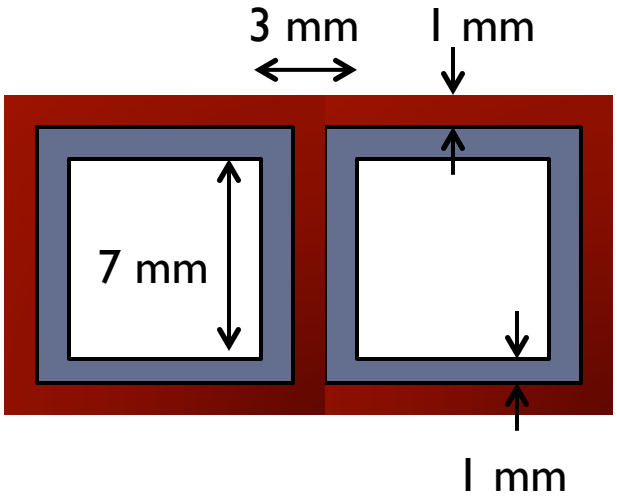
Foot Print of the Flat-Base Luneburg Lens Antenna



Waveguide Array Design

- Two Waveguide Array Designs
  - PEC Waveguide Array
    - (Red) PEC
    - (Blue) PEC
      - Up to few hundred GHz
  - High ε_r Dielectric Waveguide Array
  - (Red) Air
  - (Blue) Dielectric ε_r=50
    - Above few hundred GHz

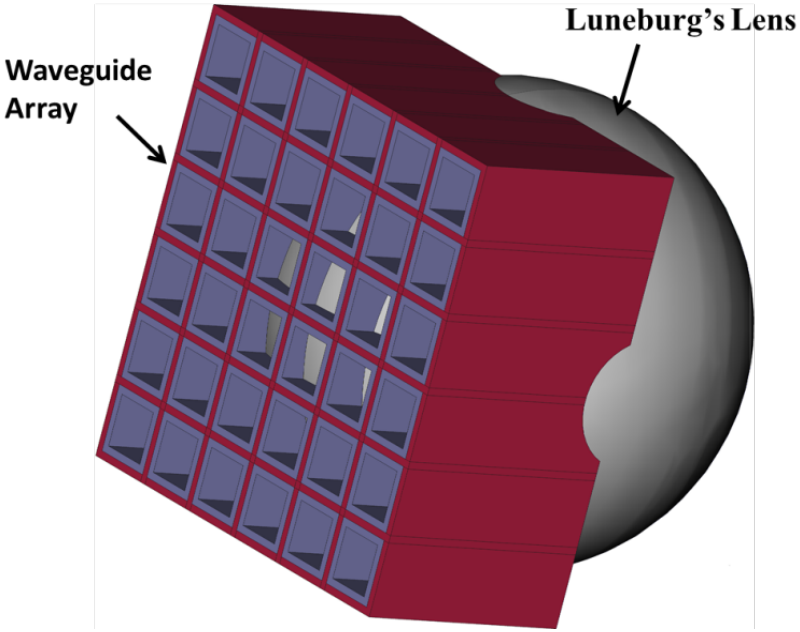


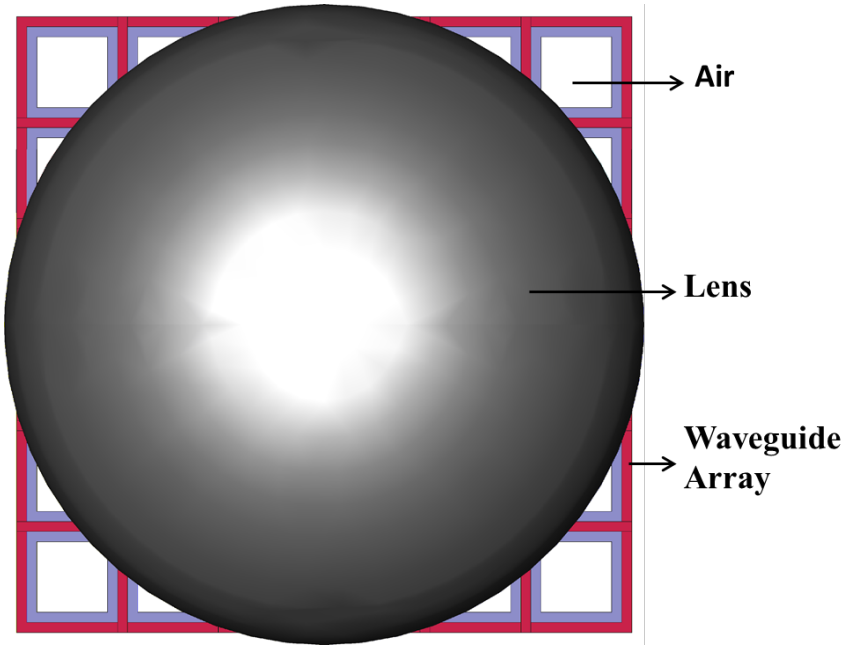


Flat-base Luneburg Lens with 6x6 Array Feed

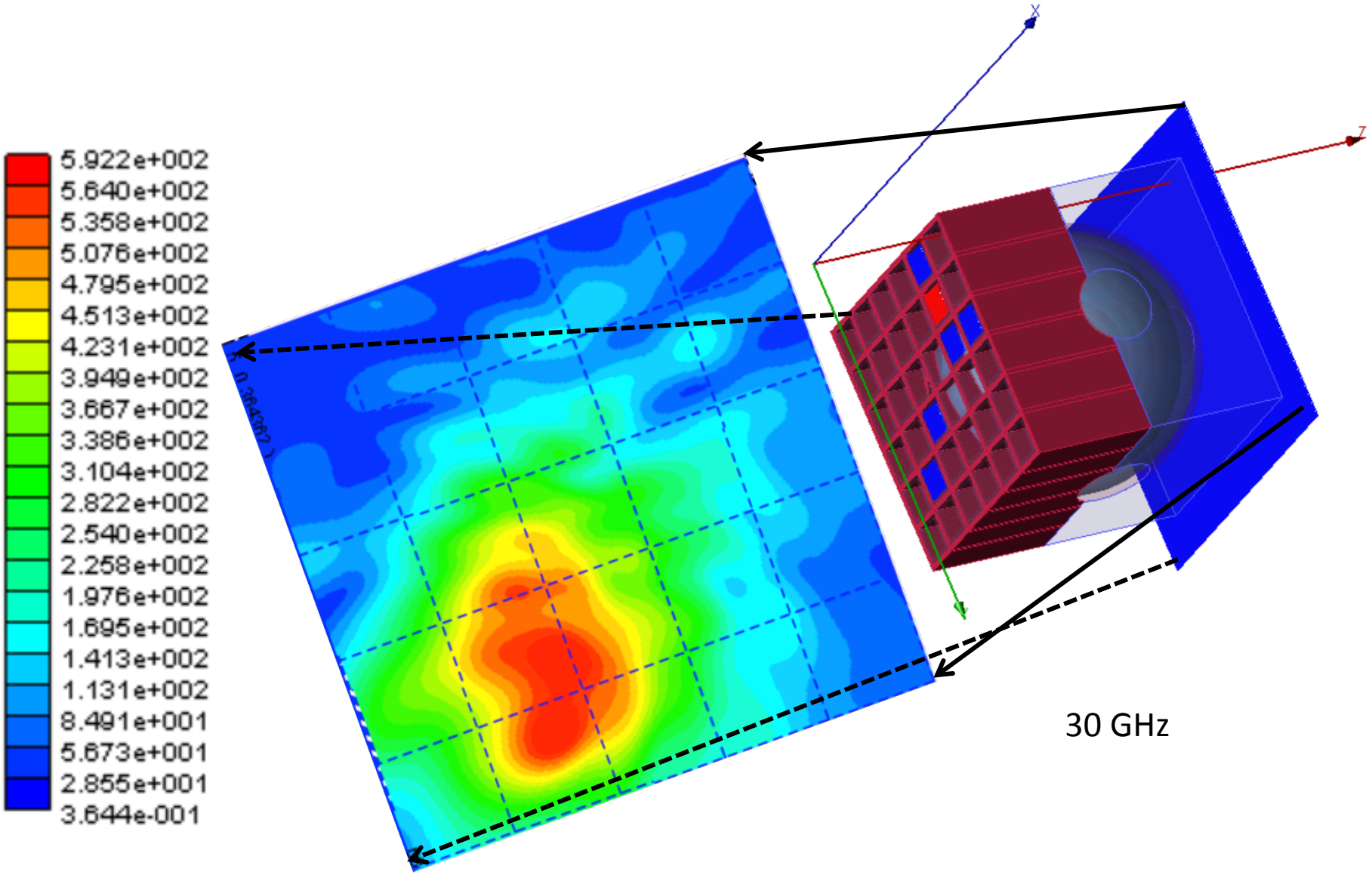
Isometric View

Top View



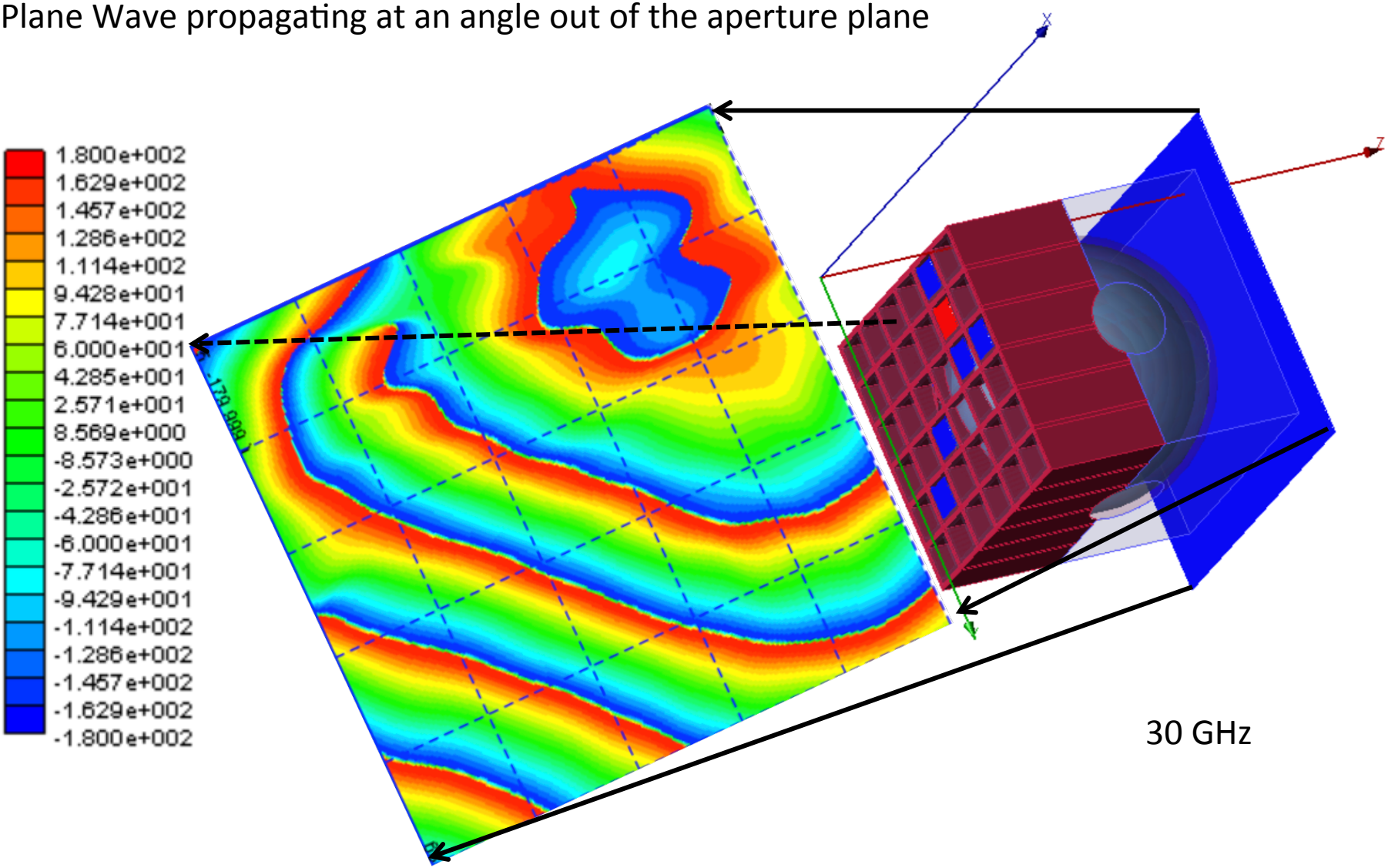


Aperture Field Amplitude (Ex)

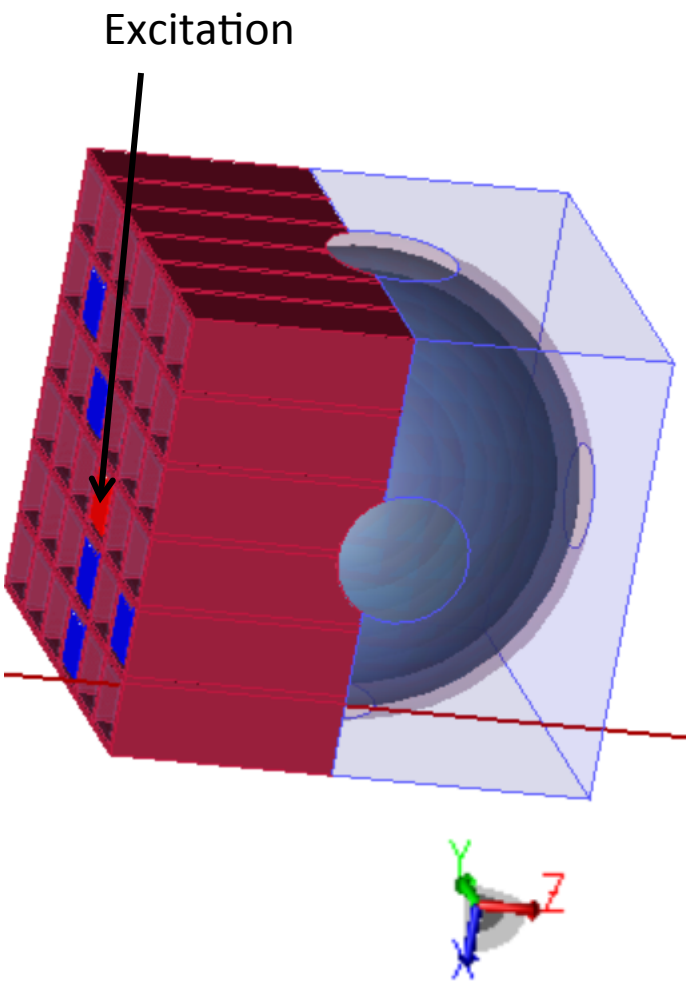


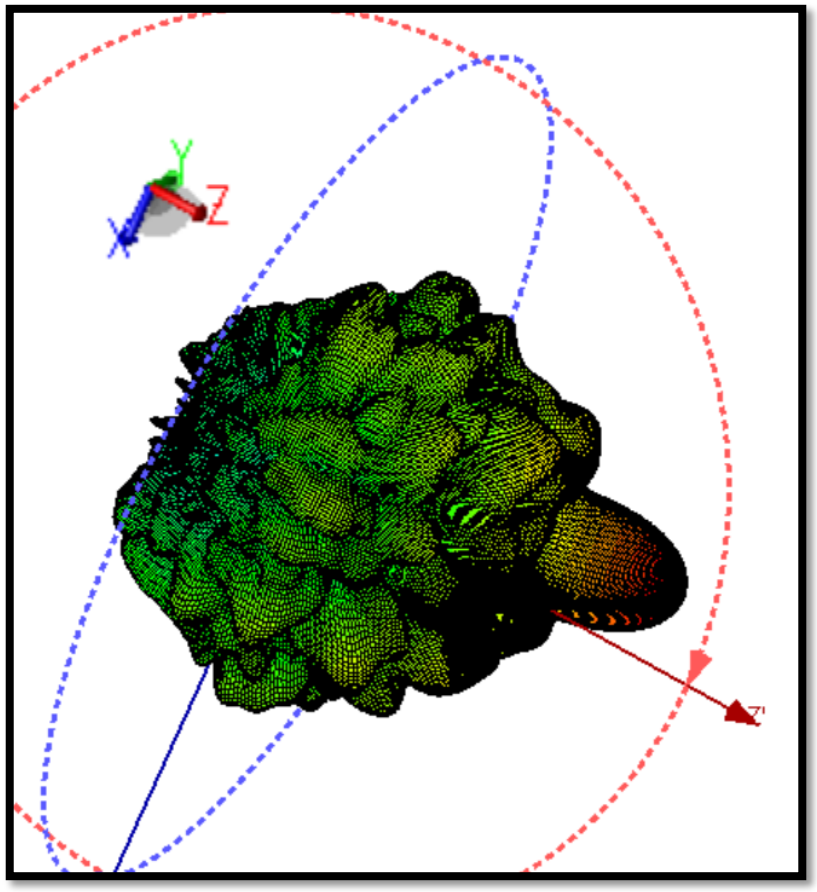
Aperture Field Phase (Ex)

Plane Wave propagating at an angle out of the aperture plane



Radiation Pattern (Gain (dBi))



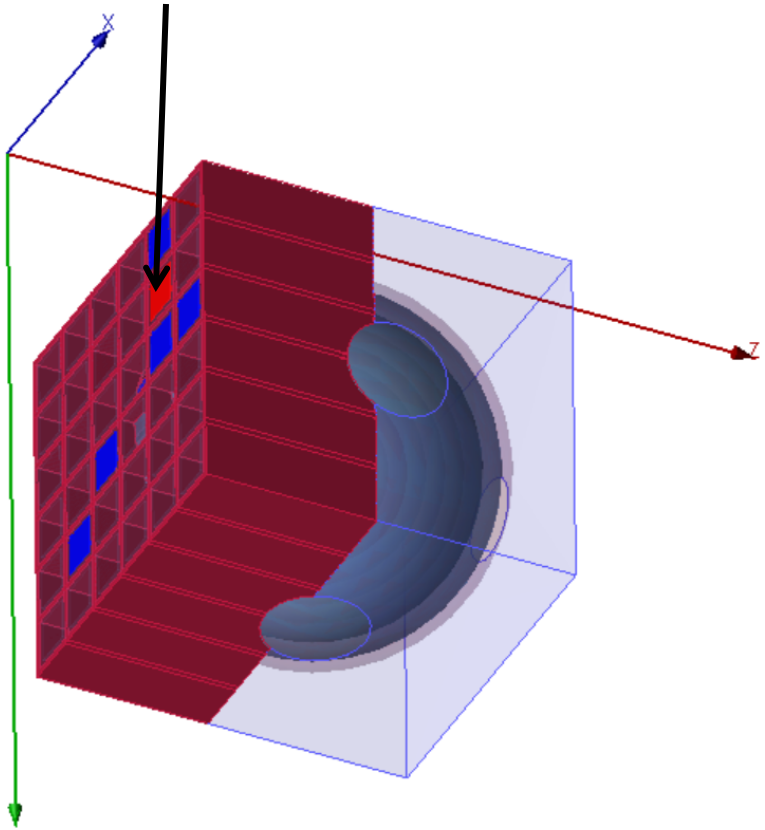


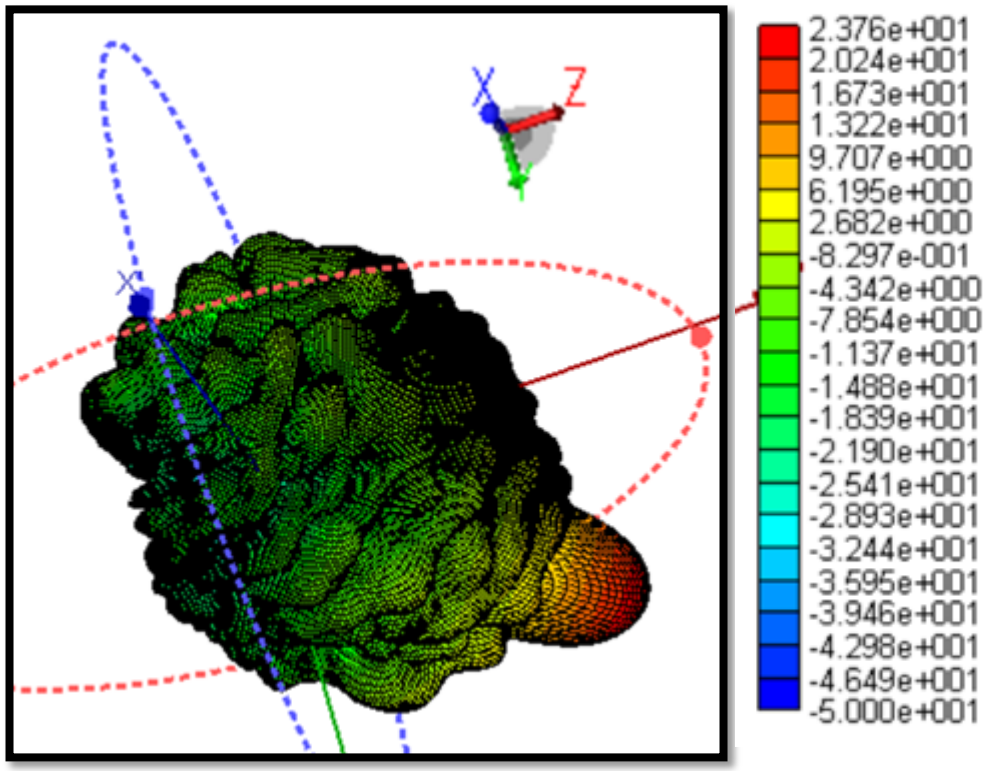
Scan Angle 12˚

30 GHz

Radiation Pattern (Gain (dBi))

Excitation



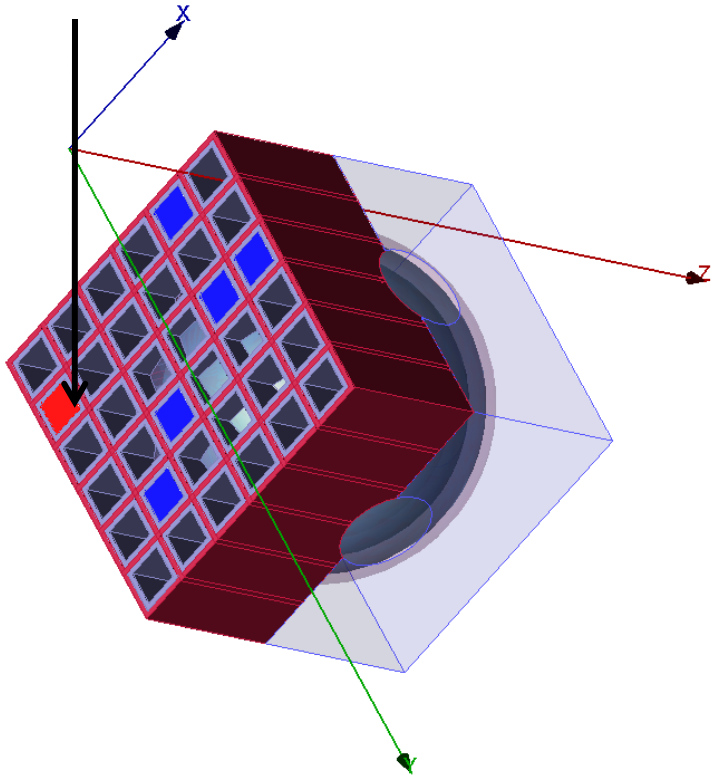


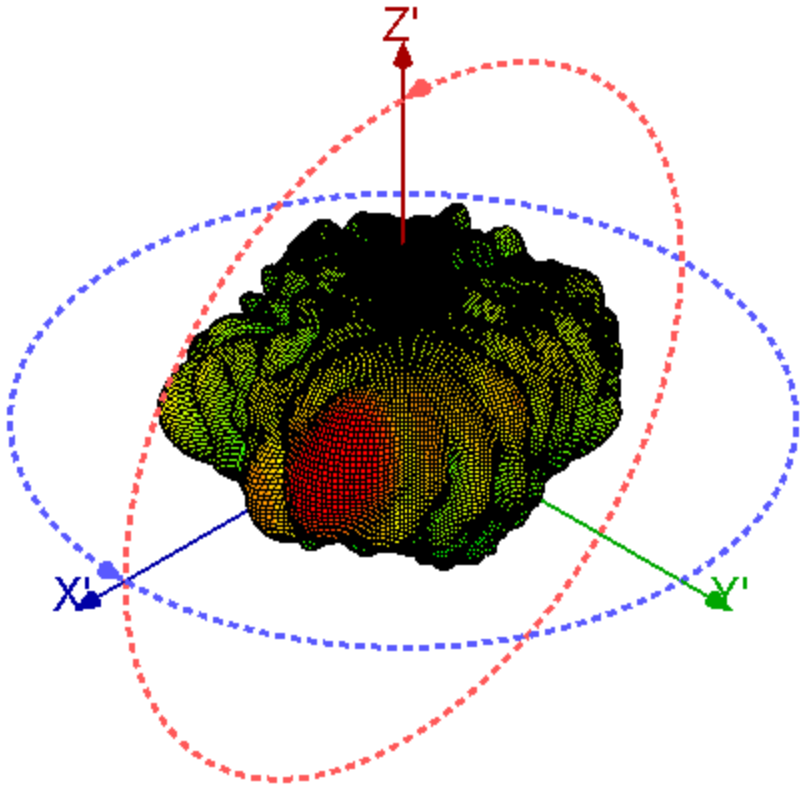
30 GHz

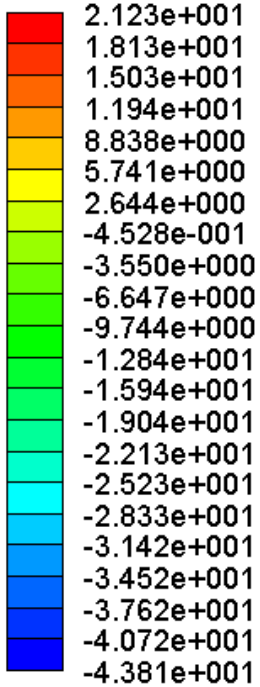
Scan Angle 41˚

Radiation Pattern (Gain (dBi))

Excitation



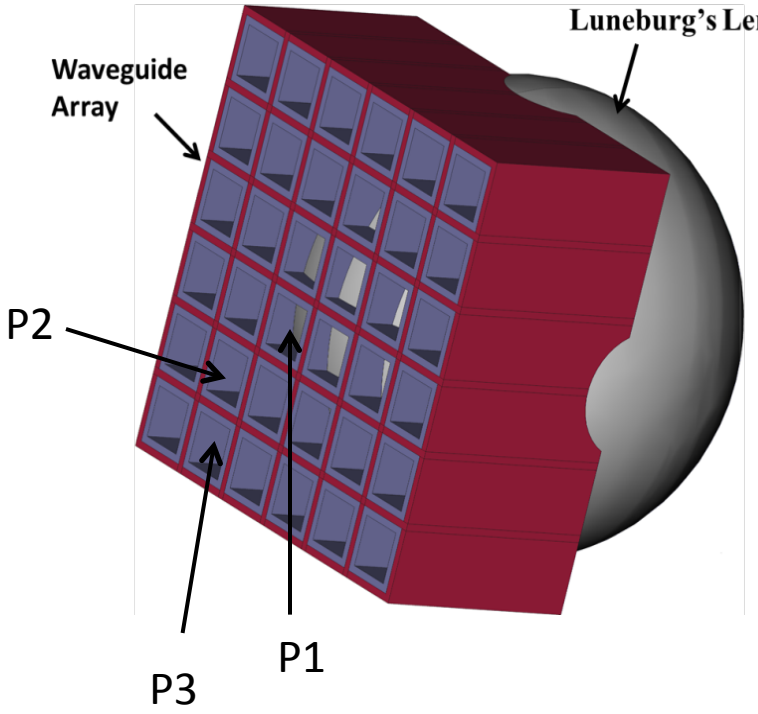


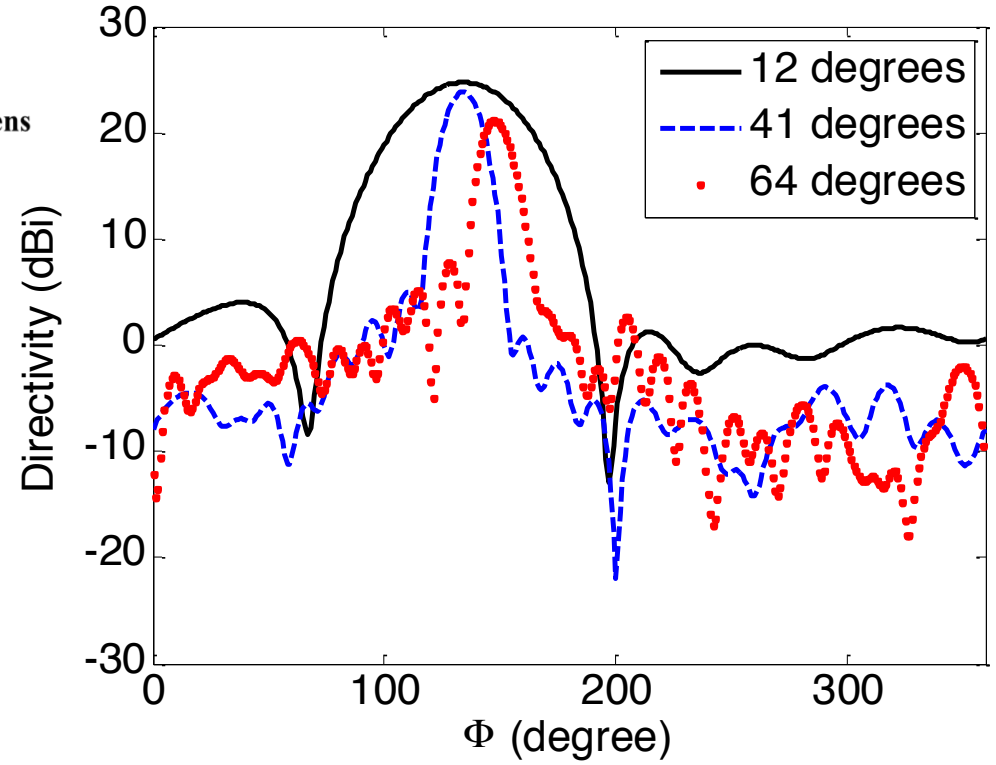


30 GHz

Scan Angle 64˚

Directivity (dBi) as a function of Φ

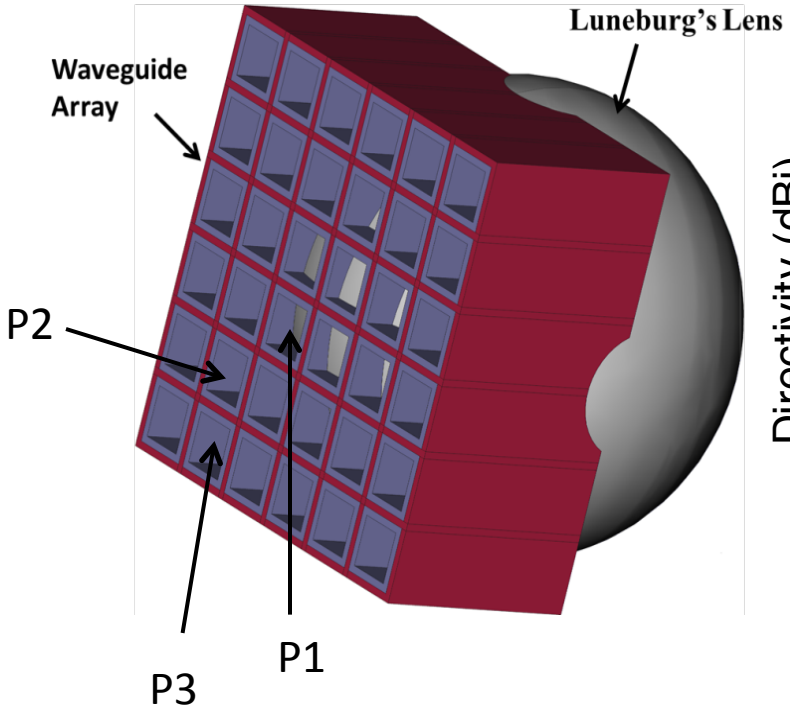


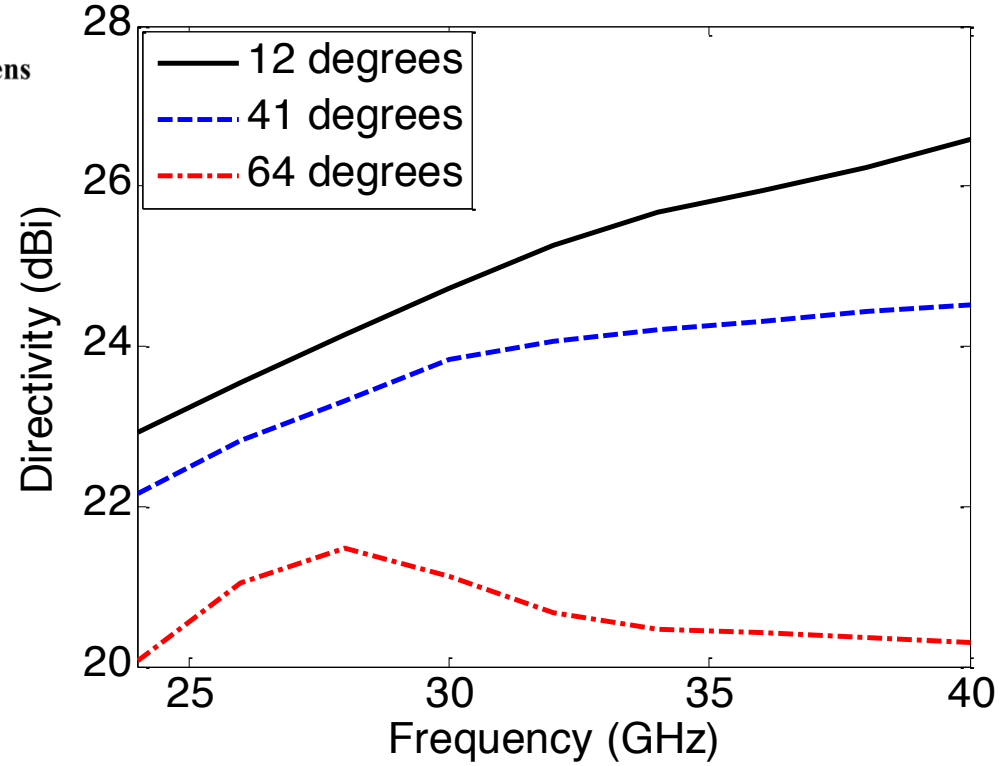


30 GHz

Scan angles of 12˚, 41˚ and 64˚ were obtained by exciting Ports P1, P2 and P3, respectively

Maximum Directivity (dBi) as a function of Frequency

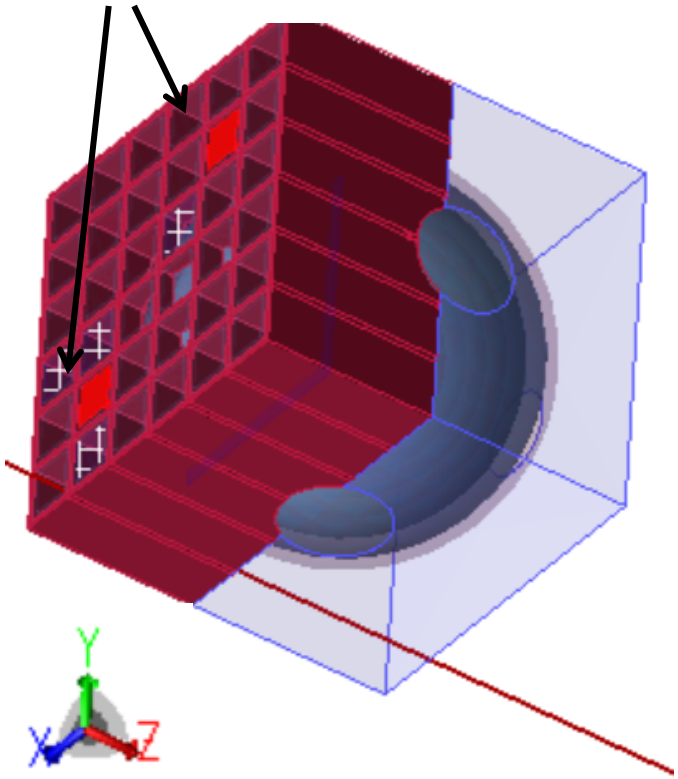


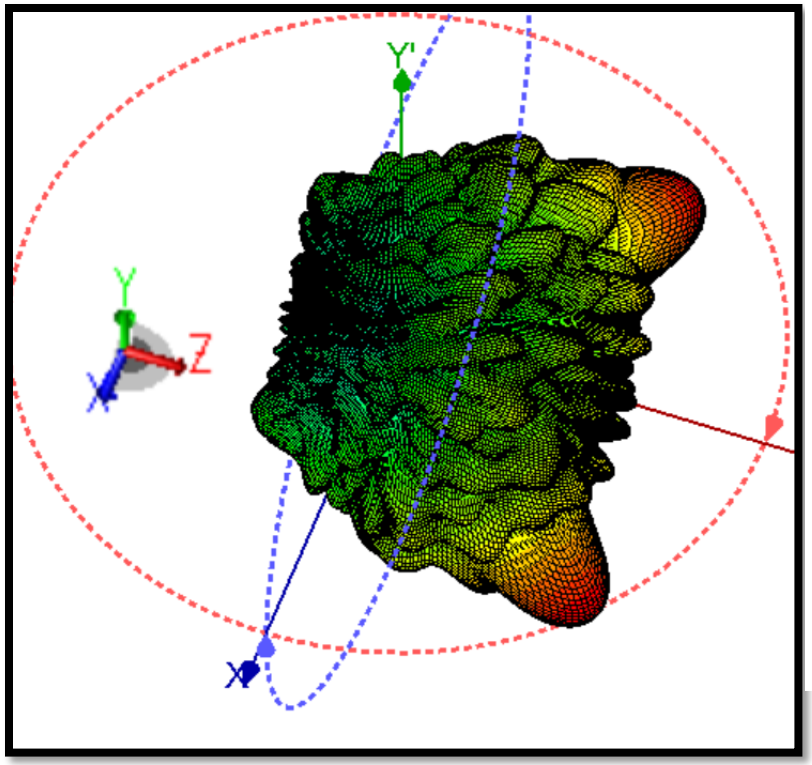


Scan angles of 12˚, 41˚ and 64˚ we obtained by exciting Ports P1, P2 and P3, respectively

Simultaneous Excitation: Radiation Pattern (Gain (dBi))

Two Ports Excited





1.867e+001
1.540e+001
1.213e+001
8.864e+000
5.594e+000
2.323e+000
-9.469e-001
-4.217e+000
-7.487e+000
-1.076e+001
-1.403e+001
-1.730e+001
-2.057e+001
-2.384e+001
-2.711e+001
-3.038e+001
-3.365e+001
-3.692e+001
-4.019e+001
-4.346e+001
-4.673e+001
-5.000e+001

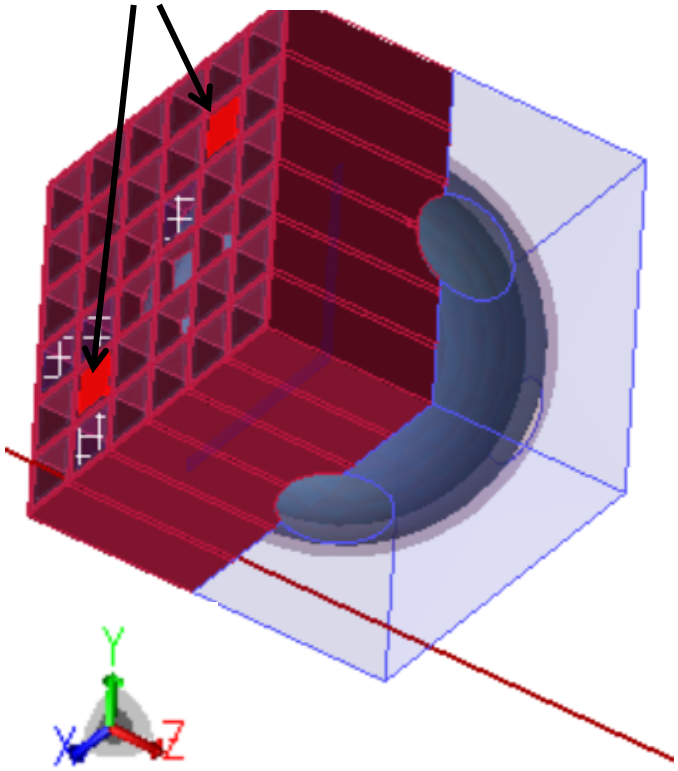
30 GHz

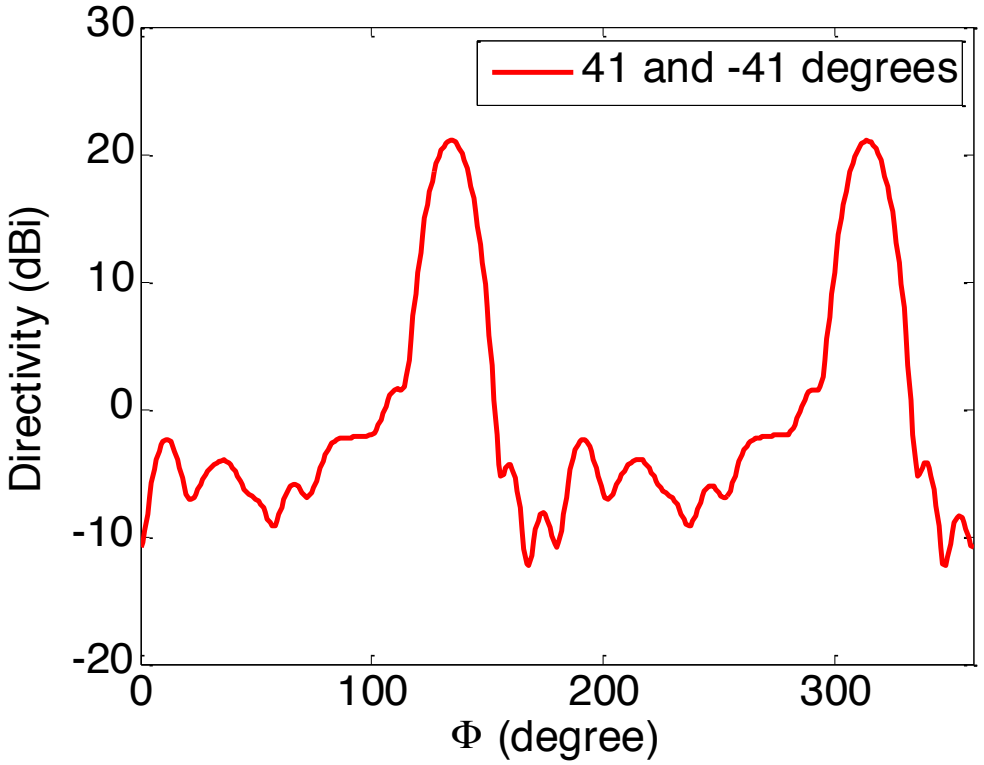
Multiple Excitations can lead to plane waves in multiple directions

Scan Angle 41˚and -41˚

Radiation Pattern (Gain (dBi))

Two Ports Excited





30 GHz

Multiple Excitations can lead to plane waves in multiple directions

Scan Angle 42˚and -42˚

Gain

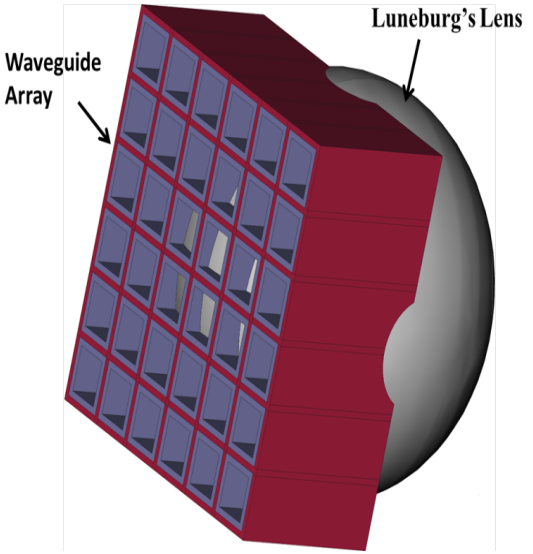
- Maximum gain (Gmax) for D=63.5 mm at 30 GHz is 25.99 dB assuming uniform field distribution in the aperture.
- Gain of our antenna (aperture size 6.35λ) is 23.75 dB for scan angle 41˚. (25.99 dBi for constant field distribution in aperture)
- Gain of Cui et al. TO lens (aperture size 5.4 lambda) is 21 dBi for scan angle of 45˚. (24.59 dBi for constant field distribution in aperture)

$G_{max} = 4\pi A_e n/\lambda^2$

Freq (GHz)	Gmax (dBi) (constant)	Gain (PEC with air gap)(dBi)	Gain(εr=50 with air gap)(dBi)	Gain (PEC)(dBi)
24	24.06	21.73	12.41	21.89
28	25.40	22.86	20.0	23.30
30	25.99	23.42	21.88	23.75
36	27.58	23.61	21.85	24.14
40	28.5	24.05	20.48	24.46

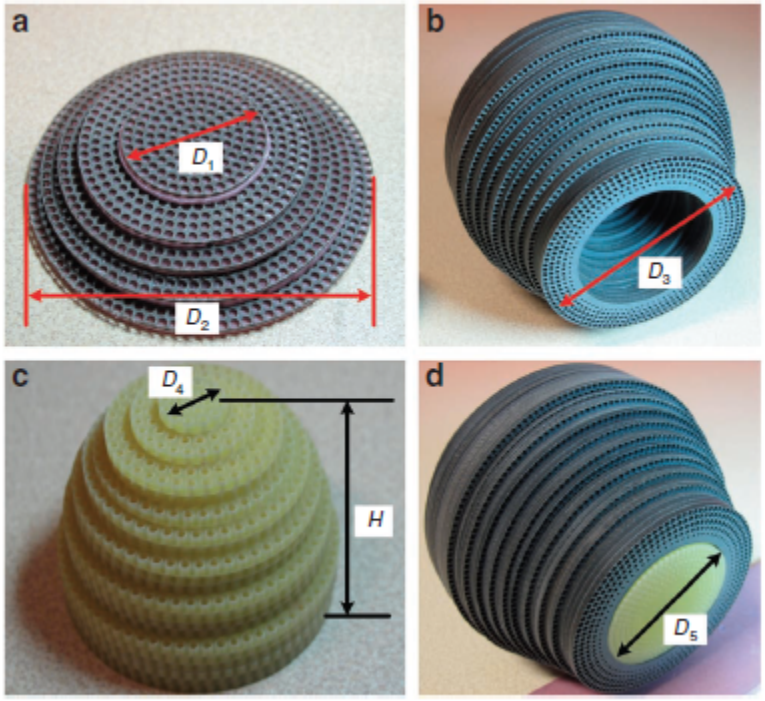
Conclusion

- The proposed Luneburg lens design can electronically scan angles as large as 64˚ both along azimuth and elevation.
- Extremely broadband as no upper cut off frequency (Lower Cut off 21.5 GHz)
- Side lobe level below 13dB (No False Alarms (due to grating lobes) as in Phased Arrays)
- The 3-dB beam width resolution for the proposed design is nearly 12˚
- Simultaneous multiple angle scan capability.
- Very high gain of 24.58 dB (constant aperture field gain 25.99 dB)
- Design for desired gain and scan angle possible by
  - Varying the aperture size
  - Varying the size of feed array
- Better performance than the flattened transformed Luneburg lens (2010 Nature Cui) in terms of gain (23.7 dB) and scan angle (30˚) for the given aperture size.

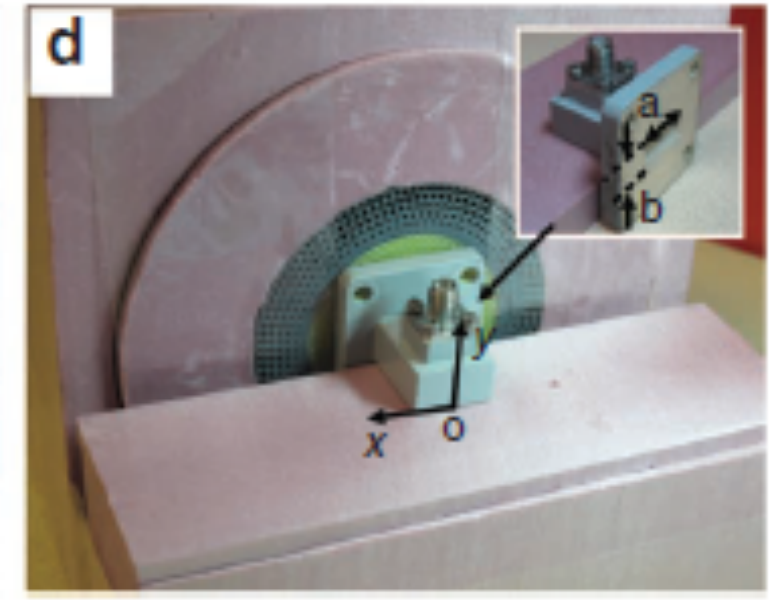


BACK UP SLIDES

Literature Survey: Exciting Using a Waveguide



Frequency of operation =12.5 to 18 GHz



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Simulated Far Field Radiation Pattern

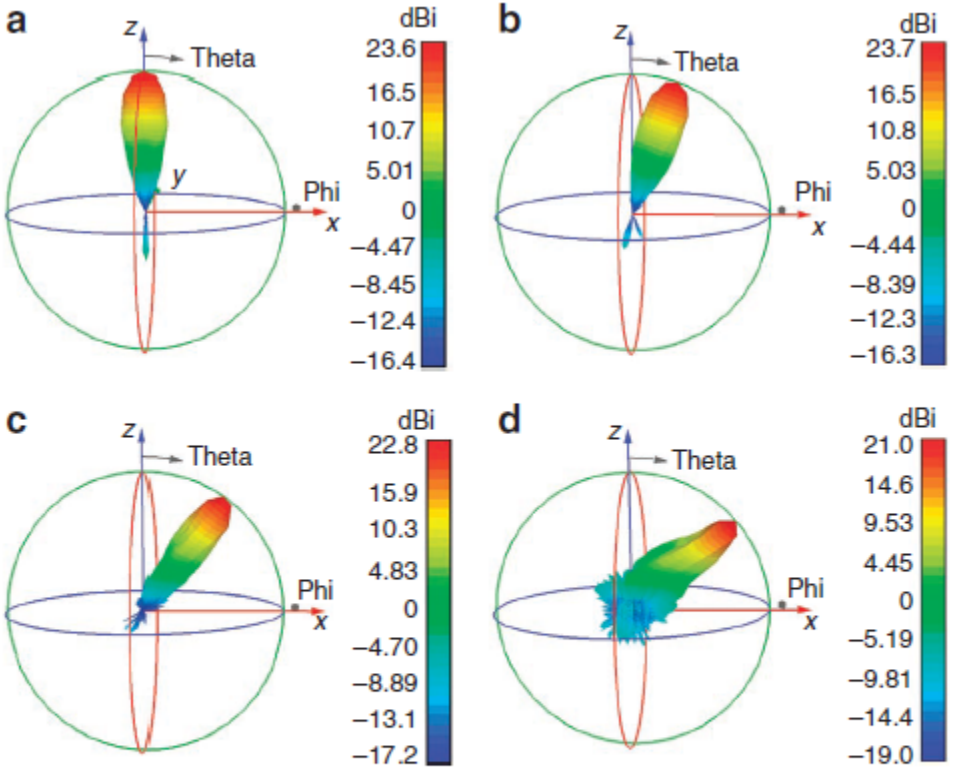

Figure 3 | Simulated 3D far-field radiation patterns of the 3D lens at 15 GHz. (**a**) The feeding source is located at the centre of the focal plane ($x = 0$ and $y = 0$). (**b**–**d**) The feeding source is located 10, 20 and 30 mm off the centre of the focal plane ($x = -10$, -20 and -30 mm, and $y = 0$).

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